

## APPARATUS AND METHOD FOR CONDUCTING FLUID IN A FUEL CELL AND FUEL CELL EMPLOYING SAME

### BACKGROUND OF THE INVENTION

#### 5 1. Field of Invention

The present invention relates to electrochemical fuel cells and more particularly to a reactant supply apparatus for a fuel cell, a fuel cell and fuel cell stack employing the same.

#### 10 2. Description of Related Art

Electrochemical fuel cells convert fuel and an oxidant to electricity and a reaction product. A typical fuel cell includes a cathode, an anode, and a membrane. The membrane is sandwiched between the cathode and anode. Fuel, in the form of hydrogen, is supplied to the anode where a catalyst, usually platinum, catalyzes the following anode reaction:



Hydrogen separates into hydrogen ions and electrons. The hydrogen (cations) migrate through the membrane to the cathode. The electrons migrate via an external circuit in the form of electricity.

An oxidant, such as pure oxygen or air containing oxygen, is supplied to the cathode where it reacts with the hydrogen ions that have crossed the membrane and with the electrons from the external circuit to form liquid water as the reaction product. The cathode reaction is also usually catalyzed by platinum and occurs as follows:



Thus the fuel cell generates electricity and water through the electrochemical reaction. Water is formed at the cathode.

Typically, the electrochemical reaction also supports a phenomenon called water pumping. As each cation (proton) migrates through the membrane, it transports or drags along several water molecules with it. Thus, there is a net transport of water to the cathode. Water pumping adds water to the product water formed at the cathode as a result of the electrochemical reaction in the fuel cell.

Solid polymer fuel cells generally comprise a Membrane-Electrode Assembly (MEA). The MEA consists of a solid polymer electrolyte or ion exchange membrane situated between and in contact with two electrodes, made of porous, electrically conducting sheet material, which act as the anode and cathode. The electrodes are typically made from carbon fiber paper or cloth. At the interface of the electrode and membrane is a layer of catalyst to facilitate the electrochemical reaction. The MEA is placed between two electrically conductive plates, commonly formed from graphite. These plates have one or more reactant flow passages impressed on their surfaces. The reactant flow passages direct the flow of a reactant to the electrode and carry away water produced at the cathode due to the fuel cell reaction and due to water pumping.

Conventional reactant flow passages are generally long, narrow and serpentine in shape. Typically, due to capillary action, water adheres to walls of the reactant flow passages, requiring considerable pressure to remove it. Failure to remove this water can result in the accumulation of water at the cathode, and this can create problems for the operation of the fuel cell. The presence of water in the vicinity of the catalyst layer reduces the accessibility of the catalyst to the reactant, a phenomenon commonly referred to as "flooding." Also, the presence of water, often in the form of droplets, can

substantially block the flow of oxidant reactant through the reactant flow passages. "Dead spots" can form in areas where channel passages are blocked. In addition, the failure to remove water from the cathode can result in localized hot spots in the membrane as the removal of water is important to cooling the fuel cell. Localized hot spots can result in pinhole failure of the membrane, for example. These conditions can result in a reduction of available power from the fuel cell, or failure in operation of the fuel cell.

### **SUMMARY OF THE INVENTION**

In accordance with one aspect of the invention, there is provided an apparatus for conducting fluid in a fuel cell. The apparatus includes a unitary gas-impermeable body having, a face having a recessed surface and a wall extending around the recessed surface, the recessed surface and the wall defining a fluid dispersion area. The apparatus further includes a plurality of spaced apart protrusions protruding from the recessed surface in the fluid dispersion area such that portions of the recessed surface extend all around each of the protrusions, each protrusion having a protrusion surface spaced apart from the recessed surface. The apparatus further includes an inlet opening, an inlet conduit, an outlet opening and an outlet conduit. The inlet conduit is in communication with the inlet opening and the fluid dispersion area to facilitate communication of fluid from the inlet opening to the fluid dispersion area and the outlet conduit is in communication with the fluid dispersion area and the outlet opening to facilitate communication of fluid between the fluid dispersion area and the outlet opening.

The recessed surface may be generally planar. It may have a generally rectangular shape, a generally trapezium shape, or it a length and a width, with the width decreasing from a first width adjacent the inlet opening to a second width adjacent the outlet opening.

The inlet conduit may include a first plurality of conduits and may include a distribution area between the inlet opening and the first plurality of conduits for distributing fluid to the first plurality of conduits for communication to the fluid dispersion area.

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The outlet conduit may include a second plurality of conduits and may include a receiving area between the second plurality of conduits and the outlet opening for receiving fluid from the second plurality of conduits for exhaust through the outlet opening.

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The body may be formed from a castable electrically-conductive corrosion-resistant material such as graphite or it may be formed from a metal coated with at least one of graphite powder, titanium, and gold.

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Each protrusion surface may have a generally curved shape or it may have at least one of a rectangular, circular and triangular shape. Each protrusion surface lies in a common plane and may be disposed approximately 0.5 to 0.8 mm from the recessed surface. The recessed surface has a total recessed surface area and each protrusion surface has a respective protrusion surface area, where a sum of the respective protrusion surface areas may be approximately equal to the total recessed surface area.

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The plurality of spaced apart protrusions may be arranged in rows and columns. Alternate columns of protrusions may be staggered relative to adjacent columns. Each protrusion may be spaced apart from adjacent contacts by a common distance.

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The body may have a groove extending around the recessed surface, for receiving a seal for sealing the face to the gas diffusion layer.

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The apparatus may include a first bridge member and the face may have a first support surface adjacent the inlet conduit for supporting the first bridge member over the inlet conduit. The groove may include groove portions adjacent the first support surface and the seal may include an inner portion operable to lie in the groove portions and the first bridge member may be operable to support the inner portion of the seal.

The body may include a plate, the face being on the plate and being generally flat. The plate may include cooling provisions and these may include parallel spaced apart grooves formed in the plate.

The protrusions may be formed in an array defining an active area of the plate and the cooling provisions may be disposed opposite the active area.

The body may have an inwardly facing side and an outwardly facing side, the recessed surface being formed in the inwardly facing side. The inwardly facing side may be operable to contact a gas diffusion layer of a membrane of the fuel cell and the grooves may be formed in the outwardly facing side to facilitate cooling.

The cooling provisions may be formed in the outwardly facing side and may include a second recessed surface and a second wall extending around the second recessed surface, the second recessed surface and the second wall defining a second fluid dispersion area. The cooling provisions may further include a second plurality of spaced apart protrusions protruding from the second recessed surface in the second fluid dispersion area such that portions of the second recessed surface extend all around each of the protrusions, each protrusion having a protrusion surface spaced apart from the second recessed surface. The cooling provisions may further include a second inlet opening operable to receive cooling fluid, a second inlet conduit, a second outlet opening and a second outlet conduit. The second inlet conduit

is in communication with the second inlet opening and the second fluid dispersion area to facilitate communication of cooling fluid from the second inlet opening to the second fluid dispersion area and the second outlet conduit is in communication with the second fluid dispersion area and the second outlet opening to facilitate communication of the cooling fluid between the second fluid dispersion area and the second outlet opening.

The apparatus may further include openings extending through the plate, adjacent the recessed surface, for receiving mounting rods therethrough, for mounting the plate in a fuel cell or fuel cell stack.

The apparatus may include a conduit opening in the body for receiving a conduit operable to conduct electrical power from the fuel cell.

In accordance with another aspect of the invention, there is provided a fuel cell stack apparatus. The apparatus includes a first fuel cell membrane assembly having a proton exchange membrane and anode and cathode gas diffusion layers on opposite sides of the proton exchange membrane. The apparatus further includes a first fluid supply apparatus comprising a gas impermeable body having a first inwardly facing side and a first outwardly facing side, the first inwardly facing side being in contact with the anode gas diffusion layer. The first inwardly facing side includes a first recessed surface and a first wall extending around the first recessed surface, the first recessed surface and the first wall defining a first fluid dispersion area. The first inwardly facing side further includes a first plurality of spaced apart protrusions protruding from the recessed surface in the fluid dispersion area such that portions of the recessed surface extend all around each of the protrusions. Each protrusion has a protrusion surface spaced apart from the recessed surface, the protrusion surfaces being operable to contact the anode gas diffusion layer. The first fluid supply apparatus further includes a first inlet opening for receiving anode reactant fluid, a first inlet conduit, a first outlet

opening and a first outlet conduit. The first inlet conduit is in communication with the first inlet opening and the first fluid dispersion area to facilitate communication of anode reactant fluid from the first inlet opening to the first dispersion area. The first outlet conduit is in communication with the first dispersion area and the first outlet opening to facilitate communication of anode reactant fluid between the first dispersion area and the first outlet opening.

The fuel cell stack apparatus further includes a second fluid supply apparatus comprising a unitary gas-impermeable body. The body has a second inwardly facing side and a second outwardly facing side, the second inwardly facing side being in contact with the cathode gas diffusion layer and having a second recessed surface and a second wall extending around the second recessed surface. The second recessed surface and the second wall define a second fluid dispersion area. The second inwardly facing side also has a second plurality of spaced apart protrusions protruding from the second recessed surface such that portions of the second recessed surface extend all around each of the protrusions, each protrusion having a protrusion surface spaced apart from the second recessed surface. The second fluid supply apparatus further includes a second inlet opening operable to receive cathode reactant fluid, a second inlet conduit, a second outlet opening and a second outlet conduit. The second inlet conduit is in communication with the second inlet opening and the second recessed surface to facilitate communication of cathode reactant fluid from the second inlet opening to the second recessed surface and the second outlet conduit is in communication with the second recessed surface and the second outlet opening to facilitate communication of excess cathode reactant fluid and cooling fluid from the cathode gas diffusion layer from the second recessed surface to the second outlet opening.

The second outwardly facing side of the second fluid supply apparatus may include cooling provisions for cooling the second fluid supply apparatus.

The cooling provisions may include a third face on the second fluid supply apparatus, the third face having a third recessed surface and a third wall extending around the third recessed surface. The third recessed surface and the third wall may define a third fluid dispersion area. The cooling provisions may further include a third plurality of spaced apart protrusions protruding from the third recessed surface in the third fluid dispersion area such that portions of the third recessed surface extend all around each of the protrusions. Each protrusion may have a protrusion surface spaced apart from the recessed surface. The cooling provisions may further include a third inlet opening for receiving cooling fluid, a third inlet conduit, a third outlet opening for draining cooling fluid and a third outlet conduit. The third inlet conduit is in communication with the third inlet opening and the fluid dispersion area to facilitate communication of cooling fluid from the third inlet opening to the third fluid dispersion area and the third outlet conduit is in communication with the third fluid dispersion area and the third outlet opening to facilitate communication of cooling fluid between the third fluid dispersion area and the third outlet opening.

The cooling provisions may comprise a plurality of parallel grooves in the outwardly facing side of the second fluid supply apparatus. The grooves may be operable to conduct cooling fluid to facilitate cooling of the second fluid supply apparatus.

The apparatus may further include first and second current collector plates in contact with the first and second fluid supply apparatuses respectively. Each of the first and second current collector plates may have an inwardly facing side and an outwardly facing side. First and second electrical conduits may be secured to at least one of the inwardly and outwardly facing sides of the first and second current collector plates respectively. First and second insulators may be disposed on the first and second conduits respectively. The first and



second conduits may be secured to the first and second current collector plates such that the first and second conduits extend through openings in components of the fuel cell and are insulated from the components by the first and second insulators, such that the first and second conduits extend from a same end of the fuel cell.

In accordance with another aspect of the invention, there is provided a fuel cell stack apparatus including a first fuel cell comprising a first membrane assembly having a first membrane and a first anode gas diffusion layer and a first cathode gas diffusion layer on opposite sides of the first membrane. The apparatus further includes first anode and first cathode fluid distribution devices for supplying anode gas and cathode gas respectively to the first anode gas diffusion layer and the first cathode gas diffusion layer respectively. The first anode and cathode fluid distribution devices have first inwardly and first outwardly facing sides respectively. The first inwardly facing side of the first anode fluid distribution device is in contact with the first anode gas diffusion layer and the first inwardly facing side of the cathode fluid distribution device is in contact with the first cathode gas diffusion layer. The first outwardly facing side of the first cathode fluid distribution device has a first plurality of grooves formed therein for conducting cooling fluid to cool the first cathode fluid distribution device.

The fuel cell stack may further include a second fuel cell comprising a second membrane assembly having a second membrane and a second anode gas diffusion layer and a second cathode gas diffusion layer on opposite sides of the second membrane. The fuel cell stack may further include second anode and second cathode fluid distribution devices for supplying anode gas and cathode gas respectively to the second anode gas diffusion layer and the second cathode gas diffusion layer respectively. The second anode and cathode fluid distribution devices may have second inwardly and second outwardly facing sides respectively. The second inwardly facing side of the

second anode fluid distribution device may be in contact with the second anode gas diffusion layer and the second inwardly facing side of the cathode fluid distribution device may be in contact with the second cathode gas diffusion layer. The second outwardly facing side of the second anode fluid distribution device may be in contact with the first outwardly facing side of the first cathode fluid supply device. The second outwardly facing side of the second anode fluid distribution device may have a second plurality of grooves formed therein, the second plurality of grooves being aligned with the first plurality of grooves on the first cathode fluid distribution device to form cooling conduits for conducting cooling fluid.

In accordance with another aspect of the invention, there is provided a fuel cell stack apparatus including at least one fuel cell comprising a first membrane assembly having a first membrane and a first anode gas diffusion layer and a first cathode gas diffusion layer on opposite sides of the first membrane. The fuel cell stack further includes first anode and first cathode fluid distribution devices for supplying anode gas and cathode gas respectively to the first anode gas diffusion layer and the first cathode gas diffusion layer respectively. The first anode and cathode fluid distribution devices have first inwardly and first outwardly facing sides respectively. The first inwardly facing side of the first anode fluid distribution device is in contact with the first anode gas diffusion layer and the first inwardly facing side of the cathode fluid distribution device is in contact with the first cathode gas diffusion layer. The fuel cell stack further includes first and second current collector plates in contact with the first and second fluid supply apparatuses respectively. Each of the first and second current collector plates has an inwardly facing side and an outwardly facing side. First and second electrical conduits may be secured to at least one of the inwardly and outwardly facing sides of the first and second current collector plates respectively. First and second insulators may be disposed on the first and second conduits respectively. The first and second conduits are secured to the first and second

current collector plates such that the first and second conduits extend through openings in components of the fuel cell and are insulated from the components by the first and second insulators, such that the first and second conduits extend from a same end of the fuel cell.

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In accordance with another aspect of the invention, there is provided a method of evacuating water from a cathode gas diffusion layer of a fuel cell membrane assembly. The method involves receiving water from the cathode gas diffusion layer in a dispersion area of a unitary gas-impermeable reactant supply apparatus having a plurality of protrusions protruding from a recessed surface extending all around each protrusion. The protrusions contact the fuel cell electrode and are sufficiently spaced apart to permit the water to flow freely past the contacts in the dispersion area. The method further involves forcing a pressurized cathode gas employed in a reaction in the fuel cell into the dispersion area in sufficient quantity to supply the cathode gas to the reaction while using excess of the cathode gas to force the water out of an outlet opening in the reactant supply apparatus, in communication with the dispersion area.

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In accordance with another aspect of the invention there is provided a fuel cell system comprising a fuel cell operable to receive fuel cell reactants and comprising a passageway for conducting cooling water therethrough and a humidifier connected to the fuel cell. The humidifier has a water inlet, a water disperser and a water outlet. The water inlet is operable to receive water from a water supply. The water disperser is operable to cause at least some of the water received at the water inlet to be absorbed into at least one reactant of the fuel cell. The water outlet is operable to receive unabsorbed water from the disperser and is in communication with the cooling passageway to direct the unabsorbed water to the cooling passageway for use in cooling the fuel cell.

The fuel cell may include first and second reactant supply openings, at least one of the reactant supply openings being in communication with the disperser to receive humidified fuel cell reactant therefrom.

5 The fuel cell may have first and second reactant supply openings and the humidifier may have first and second reactant supply ports and first and second reactant supply passages in communication with the first and second reactant supply ports respectively for receiving first and second fuel cell reactants respectively. The first and second reactant supply passages may  
10 be in communication with the first and second reactant supply openings respectively such that the first and second reactants and the cooling water are supplied to the fuel cell through the humidifier.

The water disperser may include a first plate, a water permeable membrane  
15 and a second plate. The first plate may have a plurality of channels extending between the water inlet and the water outlet. The second plate may have a plurality of channels extending between at least one of the first and second reactant supply ports and a corresponding one of the first and second reactant supply passages. The first and second plates may be disposed on  
20 opposite sides of the water permeable membrane to facilitate migration of water from the channels in the first plate to reactant in the channel in the second plate to humidify fuel cell reactant in the channels in the second plate.

Other aspects and features of the present invention will become apparent to  
25 those ordinarily skilled in the art upon review of the following description of specific embodiments of the invention in conjunction with the accompanying figures.

#### **BRIEF DESCRIPTION OF THE DRAWINGS**

30 In drawings which illustrate embodiments of the invention,

Figure 1 is an exploded side view of a fuel cell apparatus according to a first embodiment of the invention;

Figure 2 is an end view of the fuel cell apparatus shown in Figure 1;

Figure 3 is a plan view of an inwardly facing side of an anode end plate of the fuel cell apparatus shown in Figure 1;

Figure 4 is a plan view of an outwardly facing side of an anode current collector plate shown in Figure 1;

Figure 5 is a plan view of an inwardly facing side of the anode current collector plate;

Figure 6 is a plan view of an outwardly facing side of the first fluid supply apparatus of the fuel cell shown in Figure 1;

Figure 7 is a plan view of an inwardly facing side of the first fluid supply apparatus of Figure 6;

Figure 8 is a plan view of an inwardly facing side of a second fluid supply apparatus of the fuel cell shown in Figure 1;

Figure 9 is a plan view of an outwardly facing side the second fluid supply apparatus shown in Figure 8;

Figure 10 is a plan view of a cathode current collector plate of the fuel cell apparatus shown in Figure 1;

Figure 11 is a top view of the fuel cell shown in Figure 1 showing cooling provisions formed in the first and second fluid supply apparatus;

Figure 12 is a top view of a fuel cell stack according to the second embodiment of the invention showing mating grooves that form conduits to provide for cooling of fluid supply apparatus of individual fuel cells within the stack;

Figure 13 is an exploded view of a fuel cell apparatus according to an alternative embodiment of the invention in which circuit terminations of the fuel cell are disposed on a same end thereof.

Figure 14 is an exploded view of a fuel cell apparatus or optional fuel cell stack, according to a third embodiment of the invention;

Figure 15 is a plan view of an end plate of the fuel cell apparatus shown in Figure 14;

Figure 16 is a plan view of an inwardly facing side of the end plate shown in Figure 15;

Figure 17 is a plan view of an outwardly facing side of a first humidifier plate of a humidifier of the fuel cell apparatus shown in Figure 14;

Figure 18 is a plan view of an inwardly facing side of the first humidifier plate shown in Figure 17;

Figure 19 is a plan view of an outwardly facing side of a second humidifier plate of the fuel cell apparatus shown in Figure 14;

Figure 20 is a plan view of an inwardly facing side of the second humidifier plate of Figure 19;

Figure 21 is a plan view of an outwardly facing side of a third humidifier plate of the humidifier of the fuel cell apparatus shown in Figure 1;

5 Figure 22 is a plan view of an inwardly facing side of the third humidifier plate of Figure 21;

Figure 23 is a plan view of an outwardly facing side of a first current collector plate of the fuel cell apparatus shown in Figure 14;

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Figure 24 is a plan view of an inwardly facing side of the current collector plate shown in Figure 23;

Figure 25 is a plan view of an outwardly facing side of a first cooling plate of the fuel cell apparatus shown in Figure 14;

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Figure 26 is a plan view of an inwardly facing side of the first cooling plate shown in Figure 25;

Figure 27 is a plan view of an outwardly facing side of an anode fluid supply apparatus of the fuel cell shown in Figure 14;

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Figure 28 is a plan view of an inwardly facing side of the anode fluid supply apparatus shown in Figure 27;

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Figure 29 is a plan view of an inwardly facing side of a cathode fluid supply apparatus of the fuel cell shown in Figure 14; and

Figure 30 is a plan view of an outwardly facing side of the cathode fluid supply apparatus shown in Figure 29;

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Figure 31 is a plan view of an inwardly facing side of a second cooling plate of the humidifier apparatus shown in Figure 14;

Figure 32 is a plan view of an outwardly facing side of the humidifier plate shown in Figure 31;

Figure 33 is a plan view of an inwardly facing side of a second current collector plate of the fuel cell apparatus shown in Figure 14;

Figure 34 is a plan view of an outwardly facing side of the current collector plate shown in Figure 33;

Figure 35 is a plan view of an inwardly facing side of an end plate of the fuel cell apparatus shown in Figure 14; and

Figure 36 is a plan view of a second end view of the fuel cell apparatus shown in Figure 14;

Figure 37 is a top view of the humidifier and fuel cell shown in Figure 14 illustrating water humidification and cooling passages;

Figure 38 is an exploded view of a fuel cell apparatus according to a fourth embodiment of the invention in which circuit termination conduits protrude from a first end of the fuel cell apparatus; and

Figure 39 is a perspective view of an alternate configuration of an inwardly facing side of the cathode reactant supply apparatus replacing the one shown in Figure 29.



## DETAILED DESCRIPTION

Referring to Figure 1, a fuel cell apparatus according to a first embodiment of the invention is shown generally at **10** in an exploded side view. The apparatus includes a Membrane-Electrode Assembly (MEA) shown generally at **12** comprising a proton-exchange membrane **14** and anode and cathode carbon-cloth gas diffusion layers **16** and **18**, respectively, forming anode and cathode sides of the MEA, respectively. The fuel cell apparatus **10** further includes first and second fluid supply apparatus **20** and **22** operable to contact the anode and cathode gas diffusion layers **16** and **18**, respectively, and to deliver anode reactant (hydrogen gas) and cathode reactant (oxygen gas) to the anode and cathode gas diffusion layers **16** and **18**, respectively.

The first and second fluid supply apparatus **20** and **22** have inwardly and outwardly facing sides **24** and **26**, respectively. The inwardly facing sides **24** contact the anode and cathode gas diffusion layers **16** and **18**, respectively, and the outwardly facing sides **26** face outwardly away from the MEA and contact anode and cathode current collector plates **28** and **30**, respectively, in the embodiment shown. Anode and cathode end plates **32** and **34** contact the anode and cathode current collector plates **28** and **30**, respectively.

The cathode end plate **34** includes a rubber gasket **36** disposed between the cathode current collector plate **30** and the cathode end plate **34**.

The anode end plate **32** has a plurality of openings to which are secured fluid connectors, only two of which are shown at **38** and **40**, for connecting to hydrogen reactant supply and oxygen reactant exhaust conduits, respectively (not shown). Clamping members, only two of which are shown at **42** and **44**, extend across and beyond the outer perimeter of the anode and cathode end plates **32** and **34**, respectively, and are pulled together by bolts, only two of which are shown at **43** and **48**, respectively, to securely hold all the components together in tight mechanical proximity.

Referring to Figure 2, an end view of the fuel cell apparatus of Figure 1 is shown generally at 50. In this view it can be seen that the anode end plate 32 has four openings, to which are connected the hydrogen supply connector 38, oxygen exhaust connector 40 and to which are further connected a hydrogen exhaust connector 52 and an oxygen supply connector 54.

Referring to Figure 3, an inwardly facing side 46 of the anode end plate 32 is shown. The inwardly facing side 46 is flat with the exception of hydrogen and oxygen supply openings 56 and 58 and hydrogen and oxygen exhaust openings 60 and 62 in communication with the hydrogen and oxygen supply connectors 38 and 54 and the hydrogen and oxygen exhaust connectors 52 and 40, respectively. The inwardly facing side 46 abuts an outwardly facing side 47 of the anode current collector plate 28 shown in Figure 4.

Referring to Figure 4, the anode current collector plate 28 has a flat planar surface and has four rectangular openings including an oxygen supply opening 64, a hydrogen supply openings 66, a hydrogen exhaust opening 68 and an oxygen exhaust opening 70.

Referring to Figures 3 and 4, openings 56 and 66, 58 and 64, 60 and 68, and 62 and 70 are in communication with each other when sides 46 and 47 are in contact with each other.

Referring to Figure 5, an inwardly facing side 72 of the anode current collector plate 28 is shown. This inwardly facing side 72 has a generally flat planar surface with four rectangular openings 64, 66, 68 and 70 extending therethrough. This inwardly facing side 72 abuts an outwardly facing side 74 of the first supply apparatus 20 shown in Figure 6.

Referring to Figure 6, in this embodiment, the first fluid supply apparatus **20** comprises a unitary gas impermeable body in the shape of a plate about **3** mm thick. The body may be formed from a castable, electrically conductive corrosion resistant material such as graphite, for example. Alternatively, the body may be formed from a metal and be coated with graphite powder, titanium or gold, for example. The first fluid supply apparatus **20** includes four openings disposed in the four corners thereof, including hydrogen and oxygen supply openings **76** and **78**, and hydrogen and oxygen exhaust openings **80** and **82**, respectively, which are in communication with openings **66**, **64**, **68** and **70**, respectively. A groove **84** is formed in a perimeter of the outwardly facing side **74** and is operable to receive a gasket **86** therein. The gasket **86** has adjacent portions, only two of which are shown at **88** and **90**, around each opening **76**, **78**, **80** and **82**, such that portions of the gasket extending about the perimeter of the face and the adjacent portions **88** and **90** completely surround each opening **76**, **78**, **80** and **82** to seal the outwardly facing side **74** against the mating inwardly facing side **72** of the anode current collector plate **28** shown in Figure 5 to prevent escape of gas between the inwardly facing side **72** of the anode current collector plate **28** and the outwardly facing side **74** of the first fluid supply apparatus **20**.

Referring to Figure 7, the inwardly facing side **24** of the first fluid supply apparatus **20** may also be referred to as a first face side, and has a planar surface **100** and a wall **102**, defining a first generally rectangular shaped recessed surface **104**. A first plurality **106** of spaced apart contacts **108** protrude from the first recessed surface **104** such that portions of the first recessed surface extend all around each of the contacts **108**. Each contact **108** has a contact surface **110** spaced apart from the first recessed surface **104** by about **0.5** to **0.8** mm and each contact surface lies generally in the same plane as the planar surface **100**. The contacts **108** are arranged in rows and columns with adjacent columns being staggered so that fluid travelling between two adjacent contacts in a column is dispersed by a contact aligned

between the two adjacent contacts, in an adjacent column. Each contact is spaced apart from an adjacent contact by the same, common distance which may be about twice the diameter of a contact surface, for example, where the contact surfaces **110** are circular. In this embodiment, each contact surface **110** has a circular shape with a diameter of about **4.76** mm. The contact surfaces **110** may, however, be generally curved shaped, rectangular (e.g., waffle shaped), or triangular, for example. Generally, it is desirable if the total contact surface area is approximately equal to the total area between the contacts, that is, the total recessed area.

The hydrogen supply opening **76** acts as an inlet opening in the body. First and second inlet conduits **112** and **114** are formed in the first inwardly facing side **24** and establish fluid communication between the hydrogen supply opening **76** and the first recessed surface **104** to facilitate communication of reactant from the hydrogen supply opening to the first recessed surface. The first fluid supply apparatus **20** also has first and second outlet conduits **116** and **118** which establish communication between the first recessed surface **104** and the hydrogen exhaust opening **80** to facilitate communication of fluid between the first recessed surface and the hydrogen exhaust opening. The first inwardly facing side **24** is placed in contact with the anode gas diffusion layer **16** shown in Figure 1, such that a first reactant dispersion area is formed between the first recessed surface **104** and the anode gas diffusion layer whereby reactant received at the hydrogen supply opening **76** is communicated to the first reactant dispersion area and is supplied to the anode gas diffusion layer, between the contacts **108**.

The inwardly facing side **24** also has a groove **120** extending around the recessed surface **104** for receiving a polymeric seal (not shown) for sealing the face to the anode gas diffusion layer **16**. The groove may be about **4.76** mm in depth and in width, for example. Support surfaces **122**, **124** and **126** are formed in the first inwardly facing side **24** adjacent the first and second

inlet conduits **112** and **114** and are operable to support a first bridge member **128** transversely over the first and second inlet conduits **112** and **114** to support an inner portion of the seal over the first and second inlet conduits between the groove portions. A similar arrangement is provided adjacent the first and second outlet conduits **116** and **118** to support the corresponding portion of the seal thereover.

Referring back to Figure 1, in this embodiment, the proton-exchange membrane **14** is formed of a polymer sheet having a thickness of between about **0.050** mm to **0.1778** mm. The anode and cathode gas diffusion layers **16** and **18** are disposed on opposite sides of the proton exchange membrane **14** and provide gas for diffusion layers between the inwardly facing surfaces of the fluid supply apparatus **20** and **22** and the membrane **14**. The anode and cathode gas diffusion layers are composed of a cloth woven of carbon fibers, with a slurry of lampblack and a small portion of polytetrafluoroethylene (PTFE or Teflon.RTM.) impressed and sintered into the interstices of the fabric. The proton exchange membrane **14** thereby resides between cushioning "blankets" of carbon cloth infused with carbon and PTFE particles, in turn clamped between the first and second fluid supply apparatus **20** and **22**, respectively. A catalyst, usually platinum, is applied as a slurry or paste of platinum-black and lampblack in a dilute solution of the polymer of which the membrane is comprised. The catalyst may be included in the slurry applied to the surface of the gas-diffusion cloth and the membrane. The two cloth layers may then be placed next to the membrane, one on each side, and this three-layer sandwich is hot-pressed together. The polymer component of the slurry bonds to the membrane, uniting the three layers to form an integral structure called the membrane-electrode assembly (MEA).

Alternatively, an ink comprised of minute particles of platinum supported on lampblack particles may be suspended in a solution of the polymer material. The ink-slurry is applied to both surfaces of the membrane, which is then hot-

pressed to bond the ink onto the membrane. The polymer material of the ink intimately bonds to the polymer material of the membrane. The ink-coated membrane is referred to as the MEA in this approach. A layer of un-catalyzed gas diffusion cloth is then placed adjacent to each side of the membrane when the cell is assembled.

Referring to Figure 8, the inwardly facing side **24** of the second fluid supply apparatus **22** is shown generally at **130**. This side is the same as the inwardly facing side **24** shown in Figure 7. The apparatus includes oxygen supply and oxygen exhaust openings **132** and **134**, respectively, and hydrogen supply and exhaust openings **136** and **138**, respectively. The apparatus further includes a groove arrangement **140**, a recessed area **142** and contacts **144**. Pure oxygen may be received at the oxygen supply opening **132** and conducted by inlet conduits **131** and **133** into the reactant dispersion area formed between the recessed surface **142** and the cathode gas diffusion layer (**18**) for use in the fuel cell reaction. Excess oxygen not consumed by the fuel cell reaction may be conducted from the recessed surface **142** by outlet conduits **135** and **137** to the oxygen exhaust opening **134** to be evacuated through the oxygen exhaust opening.

Referring to Figures 1, 7 and 8, the first and second fluid supply apparatus **20** and **22**, respectively, co-operate with the anode and cathode gas diffusion layers **16** and **18**, respectively, such that each gas diffusion layer (**16,18**) allows reactant gas to diffuse from the dispersion area defined between it and the recessed surface **104**, **142** of its respective fluid supply apparatus (**20,22**), enabling areas (active areas) of the membrane **14** aligned with areas between the contacts **108** and **144** of the respective fluid supply apparatus to become active and generate current. Each gas diffusion layer **16,18** also forms an electrically conducting path for current generated in the active areas to flow laterally to areas where the contacts **108** and **144** of the respective fluid supply apparatus **20,22** can conduct it perpendicularly through the fuel cell or

fuel cell stack. Each gas diffusion layer **16,18** also resiliently conforms to surface irregularities on the membrane **14**, improves the electrical contact with the membrane and provides some structural support for the membrane.

5 In addition, water produced by the electrochemical reaction of the fuel cell at the cathode gas diffusion layer **18**, and any water dragged through the membrane by the hydrogen ions employed in the reaction, is received in the dispersion area, in areas between the contacts **144**. The water may fall under gravity, for example between adjacent columns or rows of contacts toward the oxygen exhaust opening **134** or may simply be directed toward the oxygen  
10 exhaust opening **134** by the flow of oxygen in the dispersion area. Desirably, the contacts **144** are spaced apart such that the surface tension of a water droplet is insufficient to maintain the water droplet between adjacent contacts, causing it to fall between the contacts, when subjected to the force of gravity, when subjected to the oxygen under pressure in the dispersion area and/or  
15 when subjected to other forces. The water is free to travel relatively unimpeded between adjacent contacts **144** and has a generally open and variable flow path allowing it to travel relatively easily within the dispersion area for evacuation through the oxygen exhaust opening **134**. Water droplets can be received anywhere in the spaces between the contacts **144** and thus  
20 flow paths of the water droplets from their point of entry into the dispersion area to the oxygen exhaust opening **134** can change as required, due to water droplets being formed in other areas of the dispersion area, to take a low impedance path to the oxygen exhaust opening **134** and to quickly clear the area at which the water was received, which allows oxygen in the  
25 dispersion area to reach the cathode gas diffusion layer (**18**). This efficient evacuation of water from the cathode gas diffusion layer (**18**) provides for a better flow of oxygen to the cathode gas diffusion layer (**18**), thereby improving the electrical output of the fuel cell apparatus **10**.

Pure oxygen may be forced into the oxygen supply opening **132** at a pressure of at least about **5-30psi** at a flow rate of about **3.9ml/minute/ampere/cell**. About **10%** of this flow is used to flush the water out of the oxygen exhaust opening **134**.

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Referring to Figure **9**, the outwardly facing side **26** of the second fluid supply apparatus **22** is formed with first and second groove arrangements **150** and **152**, respectively, which have portions surrounding the openings **132**, **134**, **136** and **138**, for receiving corresponding portions of a seal (not shown) therein. The seal is operable to contact a flat face of an inwardly facing side **154** of the cathode current collector plate **30** as seen in Figure **10**.

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Referring to Figure **10**, as described above, the inwardly facing side **154** of the cathode current collector plate **30** has a flat planar surface with no openings. The outwardly facing side (not shown) of the cathode current collector plate **30** is the same as the inwardly facing side. The inwardly and outwardly facing sides (not shown) of the cathode end plate **34** shown in Figure **1** are also flat planar with no openings.

15

Referring back to Figure **9**, the outwardly facing side **26** of the second fluid supply apparatus **22** may be formed with cooling provisions which, in this embodiment, include parallel spaced apart grooves, one of which is shown at **156** in Figure **9**. The grooves **156** are formed in an area of the body directly opposite the recessed surface (**142**) where the main source of heat to the body is focused due to the reaction that occurs between the gas delivered by the body and the cathode gas diffusion layer (**18**) that it contacts. The first fluid supply apparatus **20** may be formed with similar grooves as shown in Figure **11**.

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Referring to Figure **11**, the fuel cell apparatus shown in Figure **1** is seen from above where it will be appreciated that the grooves **156** in the first and second



fluid supply apparatus **20** and **22** are oriented parallel to each other and allow cooling air to flow therethrough to cool the respective fluid supply apparatus **20** and **22**.

5 Referring to Figure **12**, it will be appreciated that a fuel cell stack comprising a plurality of fuel cells may be produced by repeating the first fluid supply apparatus **20**, MEA **12** and second fluid supply apparatus **22** a number of times to produce a plurality of fuel cells or a fuel cell stack. One such stack having three fuel cells is shown in Figure **12**. In this embodiment, all first fluid  
10 supply apparatuses **20** and all second fluid supply apparatuses **22** are formed with the grooves shown in Figure **9** to form cooling conduits such as shown as **220** and **230**, respectively, between abutting fluid supply apparatuses. This provides for a relatively large volume of air to flow in the cooling conduits **220** and **230** to facilitate cooling.

15 Operation of the apparatus shown in Figure **1** is described as follows. Referring to Figure **2**, hydrogen received at the hydrogen connector **38** is communicated through the hydrogen supply opening **56** shown in Figure **3** to the hydrogen supply opening **66** in the current collector plate **28** shown in  
20 Figures **4** and **5**. Hydrogen emanating from the hydrogen supply opening **66** is received in the hydrogen supply opening **76** in the first fluid supply apparatus **20** shown in Figures **6** and **7** where it is channeled by the inlet conduits **112** and **114** into the dispersion area among the contacts **108** for distribution among and between the contacts for diffusion into the anode gas diffusion  
25 layer (**16**) of the MEA (**12**). Excess hydrogen is conducted by the outlet conduits **116** and **118** into the hydrogen exhaust opening **80** where it flows through the hydrogen exhaust opening **68** shown in Figures **4** and **5** and into the hydrogen exhaust opening **60** shown in Figure **3** for extraction from the hydrogen exhaust connector **52** shown in Figure **2**, at the end face of the fuel  
30 cell **10**.

Similarly, oxygen received at the oxygen supply connector **54** is conducted by the oxygen supply opening **58** shown in Figure **3** and passes through the oxygen supply opening **64** shown in Figures **4** and **5** and through the oxygen supply opening **78** shown in Figures **6** and **7** and into the oxygen supply opening **132** in the second fluid supply apparatus **22** shown in Figure **8**. The oxygen is transmitted by channels **131** and **133** into the dispersion area among the plurality of contacts **144** for dispersion into the cathode gas diffusion layer (**18**) of the MEA (**12**). Excess oxygen and any water resulting from the fuel cell reaction or dragged through the membrane assembly and received in the dispersion area is communicated by conduits **135** and **137** from the dispersion area into the oxygen exhaust opening **134** where it is communicated through the oxygen exhaust opening **82** of the anode supply plate **20** shown in Figures **6** and **7**. Oxygen in the cathode reactant exhaust opening **82** is further communicated through the corresponding oxygen exhaust opening **70** of the current collector plate shown in Figures **4** and **5** and is further communicated into the oxygen exhaust opening **62** shown in Figure **3** for extraction via the oxygen exhaust connector **40** at the end face of the fuel cell **10**.

Referring to Figure **11** as the second fluid supply apparatus **22** heats up due to energy released as a result of the fuel cell reaction, cooling air is convectively drawn into the cooling conduits **156** to help cool the second fluid supply apparatus **22**, and hence the fuel cell.

Referring to Figure **13**, an apparatus according to a second embodiment of the invention is shown generally at **300**. The apparatus is generally the same as the apparatus shown in Figure **1**, with the exception that the apparatus **300** includes an anode current collector plate **302** to which is secured a first conductor **304**. The first conductor **304** may be secured by threaded means to the anode current collector plate **302** or may be press fit therein, for example.

The apparatus **300** also includes a cathode current collector plate **306** to which is secured a second conductor **308** such as by threads or press fit means as described above. The apparatus **300** further includes a first fluid supply apparatus **310**, a MEA shown generally at **312** and a second fluid supply apparatus **314**. The apparatus **300** also includes an end plate **316**. Each of these components is formed with a respective opening therethrough and the cathode current collector plate **306** is formed with an opening therethrough for receiving the first conductor **304** therethrough such that a termination portion **318** of the first conductor **304** extends or protrudes from an end of the fuel cell. Similarly, the end plate **316** is formed with a further opening to permit the second conductor **308** to extend therethrough such that a termination portion **320** thereof extends on a same end of the fuel cell as the circuit termination portion **318** on the first conductor **304**. Insulative sleeves **322** and **324** are placed over portions of the first and second conductors **304** and **308**, respectively, which extend through the indicated components of the fuel cell to prevent unwanted electrical contact between the first or second conductor **304** and **308**, respectively, and the remaining components of the fuel cell. In this manner, both terminals or circuit termination portions **318** and **320** of the fuel cell extend on a same side or same end of the fuel cell, facilitating easy installation.

Referring to Figure **14**, a fuel cell apparatus according to a third embodiment of the invention is shown generally at **400**. In this embodiment the fuel cell apparatus includes a humidifier section shown generally at **402** and a fuel cell shown generally at **404**, first and second cooling plates **406** and **408**, first and second current collector plates **410** and **412** and first and second end plates **414** and **416**. It will be appreciated that a fuel cell stack may be formed by adding further fuel cells such as shown at **418** between the first fuel cell **404** and the cooling plate **408** or between the first fuel cell **404** and the cooling plate **406**.

In this embodiment, the fuel cell or fuel cell stack is designed to operate using hydrogen gas as the anode reactant and air to supply oxygen as the cathode reactant and employs a water cooling system.

5 Referring to Figure 15, the first end plate 414 is shown in plan view. The end plates 414 and 416 and all components between the end plates include mounting holes 420, 422, 424, 426, 428 and 430 that extend entirely therethrough. The first end plate 414 further has hydrogen supply, air supply and water supply openings shown in broken outline at 432, 434 and 436,  
10 respectively, to which are connected fluid connectors 438, 440 and 442, respectively. The first fluid connector 438 is for receiving hydrogen gas, the second fluid connector 440 is for receiving air and the third fluid connector 442 is for receiving water. The plate 414 further includes a conductor opening 444 for receiving a first conductor 446 seen best in Figure 14, the first  
15 conductor being connected to the first current collector plate 410 as will be described below.

Referring to Figure 16, an inwardly facing side of the first end plate 414 is shown generally at 450.

20 Referring to Figure 17, a plan view of an outwardly facing side 451 of a first humidifier plate 452 of the humidifier 402 shown in Figure 14, is shown. The first humidifier plate 452 includes mounting openings which are numbered the same as the mounting openings in Figures 15 and 16 to indicate coincidence therewith when the inwardly facing side 450 of the first end plate 414 and the outwardly facing side 451 of the first humidifier plate 452 are placed in contact with each other. The first humidifier plate 452 further has an oblong hydrogen conduction opening 454 and an oblong water inlet opening 456 on opposite  
25 sides of the plate. The plate 452 further includes a rounded triangular opening 458 for conducting air. The plate 452 also has a perimeter groove 460, and  
30 intermediate vertical and horizontal grooves such as shown at 462 and 464 to

form a groove arrangement, such that each of the openings in the plate is surrounded by a portion of the groove. A polymeric seal (not shown) is received in the groove to seal the side **451** shown in Figure **17**, against the side **450** shown in Figure **16**, to prevent escape of hydrogen, air or water from between the plates **450** and **452**.

Referring to Figure **18**, an inwardly facing side **465** of the first humidifier plate **452** is shown. This side **465** also includes a groove system **466**, having portions which surround each opening in the plate **452** and which are operable to receive a seal (not shown) for sealing this side **465** of the plate **452** against an outwardly facing side **467** of the second humidifier plate **482** shown in Figure **19**. Still referring to Figure **18**, the side **465** shown includes a plurality of conduits shown generally at **470** extending from the water supply opening **456** to respective water channel arrays **472**, **474** and **476** each comprised of a plurality of parallel channels extending generally widthwise across the plate and terminated in respective outlet conduits shown generally at **478**. The conduits **470** extend transversely through the groove for holding the seal and thus the groove is formed with support portions **480** adjacent the inlet and outlet conduits for supporting a respective bridge member **481**. In this embodiment, each bridge member is comprised of an elongated rectangular stainless steel planar member which extends over the conduits to support the seal. It will be appreciated that water received in the water opening **456** is operable to flow through the inlet conduits **470** and through the respective water channel arrays **472**, **474** and **476** and into the conduits **478** for conduction to a mating oblong water conduction opening **480** in the adjacent abutting second humidifier plate **482** shown in Figure **19**.

Figure **19** shows an outwardly facing side **467** of the second humidifier plate **482**. This plate **482** includes the mounting openings **420** to **430** and further includes a second oblong water opening **484**, an oblong hydrogen opening **486** and a generally triangular air opening **488**. This side **467** also includes a

groove arrangement shown generally at **490** comprising grooves which extend about each of the openings to hold a seal (not shown) for sealing the openings against the inwardly facing side **465** of the first humidifier plate **452** shown in Figure **18**. Still referring to Figure **19**, the outwardly facing side **467** of the second humidifier plate **482** includes hydrogen inlet conduits **492** that extend through a groove portion to first and second longitudinally disposed hydrogen channel arrays **494** and **496**, respectively, which are terminated in respective conduits **498** which extend through a groove portion adjacent the hydrogen opening **486** and which are in communication therewith. The portion of the groove adjacent the conduits **492** and **498** are formed with support surfaces **500** and **502** for supporting respective stainless steel rectangular bridge members **501,503** thereon for supporting portions of the seal over the conduits **492** and **498**, respectively. It will be appreciated that hydrogen received at the conduits **492** is conducted through the arrays **494** and **496**, is received in conduits **498** and is channeled into the hydrogen opening **486**.

Referring to Figures **18** and **19**, it will be appreciated that water flows through the water channel arrays **472, 474** and **476** while hydrogen flows through the hydrogen channel arrays **494** and **496**. Referring to Figures **14, 18** and **19**, a water permeable membrane **504** is disposed between the side **465** shown in Figure **18** and the side **467** shown in Figure **19** and facilitates the permeation of water from the water channel arrays **472, 474** and **476** into the hydrogen channel arrays **494** and **496** so that the hydrogen flowing in the hydrogen channel arrays becomes humidified. Thus, the hydrogen entering the hydrogen opening **486** is humidified.

Referring to Figure **20**, an inwardly facing side **505** of the second humidifier plate **482** is shown. This side **505** includes mounting openings **420** to **430** and further includes a groove arrangement shown generally at **506** which includes grooves surrounding each of the openings for receiving a seal (not shown) therein. In addition, the side **505** includes a plurality of inlet conduits shown

generally at **508** which extend through the groove adjacent the water opening **484** and in communication therewith, for conducting water to a second set of transversely disposed water channel arrays **510**, **512** and **514**. The second set of water channel arrays **510**, **512** and **514** are terminated in and are in communication with outlet conduits **516** which cross the groove portion adjacent the other water opening **480** and which are in communication therewith. Support surfaces **518** and **520** adjacent the conduits **508** and **516** are formed to support respective rectangular stainless steel bridge members **509** and **511** over the conduits **508** and **516**, respectively for supporting corresponding portions of the seal.

Referring to Figure **21**, an outwardly facing side **521** of a third humidifier plate **522** of the humidifier is shown. The third humidifier plate **522** includes the mounting openings **420** to **430** and further includes a water opening **524**, a hydrogen opening **526** and a generally triangular air opening **528**. The outwardly facing side **521** further includes a groove arrangement **530** comprising groove portions that extend to surround each opening in the plate and which is operable to receive a seal (not shown) therein. The outwardly facing side **521** of this third humidifier plate **522** includes a plurality of channels, one of which is shown at **531**, extending lengthwise along the plate from an edge **532** of the air opening **528** and in communication therewith. The channels **531** are simply terminated as shown at **534** to cooperate with and to be placed in communication with the air opening **488** in the second humidifier plate seen best in Figure **20**. The channels **531** cross respective groove portions **536** and **538** and thus the groove portions are formed with supporting surfaces such as shown at **540** and **542** adjacent each of the channels **531**, for supporting long stainless steel rectangular bridge members **541** and **543** operable to extend over all of the channels **531** to support corresponding portions of the seal (not shown) on opposite ends of the outwardly facing side **521**.

Referring to Figures **14**, **20** and **21** a water permeable membrane **550** is disposed between the inwardly facing side **505** of the second humidifier plate **482** as shown in Figure **20** and the outwardly facing side **521** of the third humidifier plate **522** as shown in Figure **21** so that water flowing in the second set of channel arrays **510**, **512** and **514** as seen in Figure **20** can pass through the water permeable membrane **550** to humidify air received in the end portions **534** of the channels **531**. Thus, air exiting through opening **528** is humidified.

Referring to Figure **22**, an inwardly facing side **543** of the third humidifier plate **522** is shown and includes a generally flat planar surface with a groove arrangement **552** having groove portions which surround each of the openings in the plate. The inwardly facing side **543** of the third humidifier plate **522** shown in Figure **22** is placed in contact with an outwardly facing side **545** of the current collector plate **410**, shown in Figure **23**.

Referring to Figure **23**, the current collector plate **410** includes mounting openings **420** to **430** and further includes the first conductor **446** which is secured such as by a press fit or by threads, for example, to the plate **410**. The plate **410** further includes a water opening **560**, an air opening **562** and a hydrogen opening **564**. The outwardly facing side **545** is smooth, flat planar to mate with the inwardly facing side **543** of the third humidifier plate **522** shown in Figure **22** such that the seal in the groove arrangement **552** shown in Figure **22** seals the openings between the plates **522** and **410** to prevent the escape of water, air or hydrogen therebetween.

Referring to Figure **24**, an inwardly facing side **547** of the current collector plate is a mirror image of the outwardly facing side **545** without the first conductor **446**.



Referring to Figure 25, an outwardly facing side **549** of the first water cooling plate **406** is shown. The first water cooling plate **406** includes the mounting openings **420** to **430** and further includes a water opening **570**, an air opening **572** and a hydrogen opening **574**. The outwardly facing side **549** further includes a groove arrangement **576** having groove portions that surround each of the openings in the plate **406** and which are operable to receive a seal (not shown) therein to seal the outwardly facing side **549** shown in Figure 25 against the inwardly facing side **547** of the current collector plate **410** shown in Figure 24.

Referring to Figure 26, an inwardly facing side **551** of the first cooling plate **406** is shown. The inwardly facing side **551** includes a groove arrangement **576** including groove portions which extend to surround each opening in the plate **406**. The inwardly facing side **551** further includes a plurality of inlet conduits **578** which cross the groove portion adjacent the opening **570** and which extend into a recessed portion bounded by a recessed surface shown generally at **580**, defined by a rectangular wall **582**. Within the area bounded by the wall **582** there are a plurality of protrusions, one of which is shown at **584**. The protrusions extend between **0.5** and **0.8** mm from the recessed surface **580** in an array of staggered rows and columns. A plurality of outlet conduits **586** is also in communication with the recessed area and the outlet conduits cross a groove portion to terminate adjacent a side of the plate **406**. Support portions shown at **590** are disposed adjacent the groove portions that are crossed by the conduits **578** and **586** to support respective elongated rectangular stainless steel bridge members **591** and **593** for supporting corresponding portions of the seal.

Referring to Figure 27, an outwardly facing side **587** of the anode fluid supply apparatus **401** is shown. The anode fluid supply apparatus **401** is formed of a body in the form of a plate having mounting openings **420** to **430** and further including elongated hydrogen openings **600** and **602** disposed in

approximately opposite corners of the plate and further including first and second water openings **604** and **606** also disposed in approximately opposite corners of the plate. The plate further includes first and second air openings **608** and **610** disposed at opposite ends thereof. In general, the outwardly facing side **587** is smooth, flat planar and is operable to mate with the inwardly facing side **551** of the cooling plate **406** shown in Figure 26.

Referring to Figure 28, the inwardly facing side **611** of the anode fluid supply apparatus **401** is shown. This side **611** includes a groove arrangement **612** comprising groove portions that extend to surround each of the openings in the plate. The inwardly facing side **611** also has a generally flat face surface **614** and a wall **616** defining a first rectangular shaped recessed surface **618**. A plurality of spaced apart protrusions which act as contacts **620** protrude from the recessed surface **618** such that portions of the recessed surface extend all around each of the contacts. Each contact **620** has a contact surface **622** spaced apart from the recessed surface **618** by about 0.5 to 0.8 mm and each contact surface lies generally in the same plane as the planar surface **614**. The contacts **620** are arranged in rows and columns with adjacent columns being staggered so that fluid traveling between two adjacent contacts in a column is dispersed by a contact aligned between the two adjacent contacts in an adjacent column. Each contact **620** is spaced apart from an adjacent contact by the same common distance which may be about twice the diameter of a contact surface, for example, where the contact surfaces are circular. In this embodiment, each contact surface has a circular shape with a diameter of about 3/16" but the contact surfaces may be generally curved shaped, rectangular, waffle shaped, or triangular, for example. Generally it is desirable that the total contact surface area is approximately equal to the total area between the contacts. The face is further formed with inlet conduits shown generally at **624** which extend between the recessed surface **618** and the hydrogen opening **600**. These conduits **624**

establish fluid communication between the opening **600** and the recessed surface **618**.

5 This side **611** of the plate also has a plurality of outlet conduits **626** between the recessed surface **618** and the second hydrogen opening **602** to establish communication therebetween. Support surfaces **628**, for example, are formed adjacent groove portions through which the inlet conduits **624** and outlet conduits **626** extend, to support elongated rectangular stainless steel bridge members **627** and **629** which are operable to support a corresponding portion of a seal (not shown) received in the groove arrangement **612**. Referring to 10 Figures **14** and **28** the inwardly facing side **611** shown in Figure **28** is operable to face an anode layer **631** of the membrane assembly **405**. Hydrogen supplied to the area between the contacts **620** from the opening **602** is operable to permeate the anode layer **627** for use in the fuel cell reaction.

15 Referring to Figure **29**, an inwardly facing side **621** of the cathode fluid supply apparatus **403** is shown. The cathode fluid supply apparatus **403** is formed of a body formed in a plate having the mounting openings **420** to **430** disposed therein and further including first and second elongated water openings **650** and **652**, first and second hydrogen openings **654** and **656** and first and 20 second air openings **658** and **660**. The inwardly facing side **621** further includes a groove arrangement **662** comprising groove portions which surround each of the openings for holding a seal (not shown). In addition, the inwardly facing side **621** has a generally flat planar surface **664** and a wall 25 **666** defining a rectangular recessed area **668** from which a plurality of contacts **670** similar to those shown in Figure **28** protrude. The contacts **670** are arranged in the same pattern as seen in Figure **28** and are of the same size and spacing, etc. Inlet conduits, one of which is shown at **672**, for example, extend between the air opening **658** and the recessed surface **668**. 30 To do this, the conduits cross groove portions of the groove arrangement **662** adjacent the air opening **658**. The face is formed with support portions **674** on

opposite sides of each conduit **672** for supporting an elongated stainless steel rectangular member **673** over the conduits to support corresponding portions of the seal. The inwardly facing side **621** further includes outlet conduits, one of which is shown at **676**, extending between the recessed surface and the air opening **660**. Again, the side **621** is formed with support surfaces such as shown at **674** adjacent the outlet conduits **676** for supporting a second elongated rectangular stainless steel bridge member **675** for supporting a corresponding portion of the seal. Referring to Figures **14** and **29**, the side **621** shown in Figure **29** is received against a cathode layer **663** of the membrane assembly **405** and air received at the opening **658** is conducted via the inlet conduits **672** to the recessed surface **668** where it is distributed among the array of contacts **670** for dispersion into the cathode layer of the membrane assembly **405**. Excess air is conducted through the outlet conduits **676** into the air outlet opening **660**.

This face side configuration is particularly useful on the cathode side of the fuel cell where the fluid received in the inlet opening is air, since the oxygen content per unit volume of air is much less than **100%** as is achievable when pure oxygen is used, as in the first embodiment. In this embodiment, air at a pressure of **5-30** psi and a flow rate of about **7ml/minute/ampere/cell** may be used to support the reaction at the fuel cell and will flush out water received in the dispersion area from the cathode gas diffusion layer.

As a result of the flushing of water facilitated by the recessed surface **668** and contact arrangement described herein, there is a good exchange of air through the dispersion area, which helps to flush nitrogen in the air through the dispersion area reducing its transit time therethrough and reducing the effects of nitrogen reacting with the cathode gas diffusion layer **663**.

Referring to Figure **30**, an outwardly facing side **671** of the cathode fluid supply apparatus **403** includes a flat face formed with a groove arrangement

680 including groove portions which extend to surround each of the openings and which hold a seal (not shown). This side 671 is further formed with a wall 682 defining a recessed surface 684 from which a plurality of protrusions 686 extend by a distance of approximately 0.5 to 0.8 mm to form an array. A plurality of inlet conduits 690 are formed to extend between the water opening 650 and the recessed surface 684 and outlet conduits 692 are formed to extend between the recessed surface and the water opening 652. Support surfaces such as shown at 694 are formed in groove portions adjacent the openings 650 and 652 to support respective bridge members 651 and 653 for supporting corresponding portions of the seal over the inlet and outlet conduits 690 and 692. The outwardly facing side 671 the cathode fluid supply apparatus 403 abuts an inwardly facing side of the second cooling plate 408, as shown at 699 in Figure 31. The second cooling plate 408 includes the mounting openings 420 to 430 and further includes a hydrogen opening 700, an air opening 702 and a water opening 704. In general, the inwardly facing side 699 is flat planar.

Referring to Figure 32, an outwardly facing side of the second cooling plate 408 is shown generally at 705 and includes a groove arrangement as shown at 710 for receiving a seal (not shown). The outwardly facing side 705 abuts an inwardly facing side 711 of the second current collector plate 412 as shown in Figure 33. The second current collector plate 412 includes the mounting openings 420 to 430 and further includes a hydrogen opening 712, an air opening 714 and a water opening 716. In general the inwardly facing side is flat planar.

Referring to Figure 34, an outwardly facing side 717 of the second current collector plate 412 is shown. This outwardly facing side is a mirror image of the inwardly facing side shown in Figure 33 with the exception that it includes a second conductor 720 extending at right angles from the smooth flat planar face of the outwardly facing side 717 of the second current collector plate 412.

Referring to Figure 35, an inwardly facing side **721** of the second end plate **416** is shown. The second end plate has mounting openings **420** to **430** and further includes a conduit opening **726** for receiving the second conduit **720** shown in Figure 34, a hydrogen exhaust opening **728**, an air exhaust opening **730**, and a water exhaust opening **732** as shown. Otherwise, the inwardly facing side **721** is smooth flat planar.

Referring to Figure 36, an outwardly facing side **733** of the second end plate **416** is shown. This side **733** includes a hydrogen exhaust connector **738** in communication with the hydrogen exhaust opening **728**, an air exhaust connector **740** in communication with the air exhaust opening **730** and a water exhaust connector **742** in communication with the water exhaust opening **732**. It will be appreciated that the conductor **720** shown in Figure 34 will extend through the opening **726** out of the plane of the page, toward the reader.

Operation of the fuel cell according to this fourth embodiment shown in Figures 14 to 36 will now be described.

Referring to Figures 14 and 15, hydrogen received at the hydrogen supply connector **438** is received through the hydrogen opening **432** shown in Figures 15 and 16 and is transmitted through the hydrogen opening **454** shown in Figures 17 and 18 and is received in the conduits **492** in the outwardly facing side **467** of the second cooling plate **482** shown in Figure 19. The hydrogen flows through the hydrogen channel arrays **494** and **496** and is collected by conduits **498** and channeled into the hydrogen opening **486**.

Referring to Figures 20 and 21, hydrogen in the hydrogen opening **486** is communicated to the hydrogen opening **526** in the third cooling plate **522** and referring to Figures 22 and 23, is further conducted through the hydrogen opening **564** in the current collector plate **410** shown in Figure 23.

Referring to Figures **24** and **25**, hydrogen in the hydrogen opening **564** is communicated to the hydrogen opening **574** in the third cooling plate shown in Figures **25** and **26** and is further conducted into the hydrogen opening **602** in the anode fluid distribution plate **401** shown in Figures **27** and **28**. Hydrogen received in the opening **602** is communicated through conduits **626** to the recessed area **618** where it is dispersed among the contacts **620** for dispersion into the anode gas diffusion layer **631** of the membrane assembly **405**. Excess hydrogen is conducted through the outlet conduits **624** to the hydrogen opening **600** where it is communication through an opening (not shown) in the membrane assembly to the hydrogen exhaust opening **654** in the second fluid supply apparatus **403** shown in Figures **29** and **30**. Hydrogen in the hydrogen exhaust opening **654** is communicated to the hydrogen exhaust opening **700** in the second cooling plate **408** shown in Figures **31** and **32** and is further communicated into the hydrogen exhaust opening **712** in the second current collector plate **412** shown in Figures **33** and **34**. Hydrogen in the hydrogen exhaust opening **712** is further communicated to the hydrogen exhaust opening **728** in the second end plate **416** shown in Figures **35** and **36** where it is operable to exit the fuel cell through the hydrogen exhaust connector **738** shown in Figure **36**.

Referring back to Figures **14** and **15**, air received at the air inlet connector **440** is communicated to the air supply opening **434** in the first end plate **414** shown in Figures **15** and **16**. Air received in the air supply opening **434** is communicated to the air opening **458** in the first humidifier plate **452** shown in Figures **17** and **18** and is further communicated to the air opening **488** in the second humidifier plate **482** shown in Figures **19** and **20**. Air in the air opening **488** is further communicated to the air channel terminations **534** in the third humidifier plate shown in Figure **21**. Air received in these channel terminations is conducted by the channels **531** in a direction from right to left across the page toward the air exhaust opening **528** in the third humidifier

plate **522** shown in Figure **21**. Air received in the air exhaust opening **528** is communicated to the air exhaust opening **562** in the first current collector plate **410** shown in Figures **23** and **24** and is further communicated to the air exhaust opening **572** in the third cooling plate **406** shown in Figures **25** and **26**. The air is further communicated into the air supply opening **608** of the first fluid supply apparatus **401** shown in Figures **27** and **28** and is further communicated to the air supply opening **658** of the second fluid supply apparatus shown in Figures **29** and **30**. Air received in the air supply opening **658** is communicated through the inlet conduits **672** into the dispersion area among the contacts **670** where it is operable to diffuse into the cathode gas diffusion layer **663** of the membrane assembly.

Water received from the cathode gas diffusion layer as a result of the fuel cell reaction or as a result of hydrogen dragging water through the membrane, is exhausted through the outlet conduits **676** and gathered at the air exhaust opening **660**. Air gathered at the air exhaust opening **660** is communicated to the air exhaust opening **702** in the second cooling plate **408** shown in Figures **31** and **32** and is further communicated through the air exhaust opening **714** in the second current collector plate **412** shown in Figures **33** and **34** and is received at the air opening **730** in the second end plate shown in Figures **35** and **36**. Air received at the air exhaust opening **730** is exhausted from the fuel cell through the air exhaust connector **740** shown in Figure **36**.

Referring back to Figures **14** and **15**, water received at the water supply connector **442** is communicated to the water supply opening **436** in the first end plate **414** shown in Figures **15** and **16**. From the water supply opening **436**, the water is communicated through the water supply opening **456** in the first cooling plate **452** shown in Figures **17** and **18**. Water received in the water supply opening **456** is communicated via the conduits **470** through the water channel arrays **472**, **474** and **476** and is communicated via the outlet conduits **478** to a water supply opening **480** in the second humidifier plate **482**



shown in Figures 19 and 20. At the same time, water in the water supply opening 456 is communicated to the water supply opening 484 in the second humidifier plate 482 shown in Figures 19 and 20 and is channeled by inlet conduits 508 through the second set of water channel arrays 510, 512 and 514 to be captured by the outlet conduits 516 and communicated to the water supply opening 480.

As described above, water flowing through the water channel arrays 472, 474 and 476 is operable to pass through the water permeable membrane between faces 465 shown in Figures 18 and 467 shown in Figure 19 to cause hydrogen flowing through the channel arrays 494 and 496 in the second humidifier plate 482 shown in Figure 19 to be humidified. Similarly, water flowing in the second set of water channel arrays 510, 512 and 514 is operable to pass through a second water permeable membrane between the face 505 of the second cooling plate 482 shown in Figure 20 and face 521 of the third cooling plate 522 shown in Figure 21 to permit air flowing in the channels 531 to become humidified such that air received in the air supply opening 528 is humidified air.

Returning to the description of the flow of water through the fuel cell, water received in the water supply opening 480 passes through the water supply opening 524 in the third humidifier plate 522 shown in Figures 21 and 22 and is further conducted into the water supply opening 560 in the current collector plate 410 shown in Figures 23 and 24. Water received in the opening 560 is communicated to the water supply opening 570 in the first cooling plate 406 shown in Figures 25 and 26.

Referring to Figure 26, water received in the water supply opening 570 is conducted by inlet conduits 578 to the array of protrusions 584 where it is dispersed among the protrusions to extract heat therefrom. The water is received by the outlet conduits 586 and is communicated to the water exhaust

opening **606** in the first fluid supply apparatus **401** shown in Figures **27** and **28**. At the same time, a portion of the water received in the opening **570** in the first cooling plate **406** shown in Figure **26** is communicated to the water supply opening **604** in the first fluid supply apparatus **401** shown in Figures **27** and **28**. Water in the openings **604** and **606** is communicated through corresponding openings in the membrane (not shown) and further through corresponding openings **650** and **652**, respectively, in the second fluid supply apparatus **403** shown in Figures **29** and **30**.

Referring to Figure **30**, water received in the opening **650** is communicated via inlet conduits **690** into the dispersion area among the protrusions **686** and is received at outlet conduits **692** and communicated to the second water opening **652**. Water received at the second water opening **652** is communicated through the water exhaust opening **704** in the second cooling plate **408** shown in Figures **31** and **32**. Water in the water exhaust opening **704** is communicated through the water exhaust opening **716** in the second current collector plate **412** shown in Figures **33** and **34** and is further communicated to the water exhaust opening **732** in the end plate shown in Figures **35** and **36**.

Referring to Figure **36**, water received in the water exhaust opening **732** is exhausted from the fuel cell through the water exhaust connector **742**.

Referring to Figure **37**, from the foregoing it will be appreciated that the openings **570**, **604** and **650** in components **406**, **401** and **403** act as a first portion **733** of a passageway for the conduction of cooling water through the fuel cell. In addition openings **606**, **652**, **704**, **716** and **732** act as a second portion **735** of the passageway. The recessed surfaces **580** and **684** in components **406** and **403** also act as part of the passageway by communicating water from the first portion **733** to the second portion **735** of the passageway. Cooling water is supplied to the first portion **733** of the

passageway through the opening **560** in the plate **410** interposed between the humidifier **402** and the fuel cell.

5 The opening **456** in humidifier plate **452** acts as a water inlet, and the arrays **472, 474, 476** and **510, 512, 514** in the first and second humidifier plates **452** and **482** respectively act as a water disperser **737** operable to cause at least some of the water received at the water inlet to be absorbed into at least one reactant of the fuel cell. Opening **524** acts as a water outlet operable to receive unabsorbed water from the water disperser and is in communication with the first portion **733** of the cooling passageway in the fuel cell (via the plate **410** in this embodiment) to direct the unabsorbed water to the cooling passageway for use in cooling the fuel cell. Thus, a single water supply may be provided to the humidifier **402** and excess, unabsorbed water in the humidifier is directed into the fuel cell for use in cooling the fuel cell. A suitable flow rate of water may be supplied to the humidifier to ensure that sufficient water is provided to the fuel cell for cooling.

Referring to Figure **38**, a fuel cell according to an alternative embodiment of the invention is shown generally at **800**. The fuel cell of this arrangement is similar to the fuel cell shown in Figure **14** with the exception that it includes a second current collector plate **814** having a conductor **818** connected to an inwardly facing side **820** thereof so that the conductor **818** extends on the same end of the fuel cell as a conductor **807** connected to the first current collector plate **806**.

25 In this embodiment, the fuel cell is comprised of a first end plate **802**, a humidifier section **804**, a first current collector plate **806**, a cooling plate **808**, a fuel cell module **810**, the second cooling plate **812**, a second current collector plate **814** and an end plate **816**. The first current collector plate **806** has a first conductor **807** secured thereto to extend from an outwardly facing side **809** thereof. The end plate **802** and the humidifier components **804** have

respective openings which are aligned to permit the conductor **807** to extend therethrough. An insulator **811** is placed over the conductor **807** to insulate it from the first end plate **802** and the humidifier components **804**. The first end plate **802**, all components of the humidifier **804**, the first current collector plate **806**, the first cooling plate **808**, the fuel cell module **810** and the second cooling plate **812** also each have respective openings therethrough which are aligned to receive the second conductor **818** therethrough. An insulator **822** is placed over the second conductor **818** to insulate it from the respective components **802**, **804**, **806**, **808**, **810** and **812**.

The conductors **807** and **818** extend or protrude from a same end of the fuel cell **800** and facilitate easy connection of electrical components to the conductors from the same end of the fuel cell. It will be appreciated that by suitable reversal of the conductors **807** and **818** to extend in opposite directions from their respective plates and by adjusting the lengths of these conductors appropriately and by forming openings in appropriate intervening components, the conductors **807** and **818** may be caused to extend from the opposite end of the fuel cell.

Referring to Figures **29** and **39**, the face configuration of the second fluid supply apparatus **403** shown in Figure **29** may alternatively be replaced with the face configuration shown in Figure **39**. In this replacement configuration, a second fluid supply apparatus **820** has mounting openings **420**, **422**, **424**, **426**, **428** and **430** and further has water openings **650**, **652** and hydrogen openings **654** and **656** similar to those shown in Figure **29**. In addition, the apparatus **820** includes a groove arrangement **662** generally the same as that shown in Figure **29**, for holding a seal therein.

In this embodiment, the apparatus **820** further includes a recessed surface **850** having a generally trapezium shape defined by a length indicated by arrow **852**, a first width indicated by arrow **854** and a second width indicated

by arrow **856**. The second width **856** is less than the first width **854** and continually decreases from an inlet end **858** of the apparatus **820** to an outlet end **860** thereof. In this embodiment, air entering an inlet opening **862** in the apparatus is directed by an adjacent recessed surface **864** into a plurality of inlet channels **866** for distribution into a dispersion area **868** where the air is dispersed among an array of contacts **870**. The decreasing width of the recessed surface **850** helps to maintain a relatively constant pressure of air throughout the dispersion area **868** and excess air and water formed by the fuel cell reaction and water dragged through the membrane assembly is channeled through outlet conduits, one of which is shown at **872**, into an outlet recessed surface **874** which acts as a receiving area to collect and channel air and water toward an outlet opening **876**.

From the foregoing, it will be appreciated that a dispersion area according to the invention described herein may be used to disperse hydrogen, air, oxygen and/or water on various faces of components of a fuel cell to perform fluid distribution functions and to collect fluid for exhaust from the fuel cell to prevent flooding. In addition, various air and water cooling methods and apparatus have been described and useful circuit termination configurations are described.

While specific embodiments of the invention have been described and illustrated, such embodiments should be considered illustrative of the invention only and not as limiting the invention as construed in accordance with the accompanying claims.